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Technical Report Lab Access User Project

Renewable Energy Community "Energy City Hall"
of the City of Magliano Alpi (Italy)
(M-ECHall #107)

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Table of Contents

List of Figures

List of Abbreviations

CO	Project Coordinator
EC	European Commission
LA	Lab Access
UG	User Group
UP	User Project
REC	Renewable Energy Communities
MV	Medium Voltage
LV	Low Voltage
DB	Database
PV	Photovoltaic Plant

Executive Summary

Renewable Energy Communities (REC), introduced in 2019 by the Clean Energy for all Europeans Package, are new legal entities that promote citizens involvement in energy production and management. They are considered a key instrument in driving the energy transition at a local level, supporting the use of renewable energy and contributing to limit fuel poverty through reduced energy consumption and lower tariffs.

RECs have been introduced in the Italian regulation in 2019 as associations of citizens, small and medium-sized enterprises, and public entities who are equipped with shared assets for generation and local self-consumption of renewable energy. The RECs are based on open participation and aim to bring environmental, economic and social benefits to their members and to the area in which they operate. To support the communities, the Italian legislation envisages a contribution of 110€/MWh for the energy that is self-consumed within the REC, evaluated according to a "virtual" scheme.

The user group, i.e. the Renewable Energy Community of Magliano Alpi, is one of the first RECs created in Italy and is interested in tackling some of the most relevant technical and engineering challenges associated to operation and expansion of the RECs. In particular, the Magliano Alpi team is interested in developing new forecast models for the energy profiles of the communities that can support the planning and expansion of the RECs and provide robust quantitative information for the development of business plans. This point is particular relevant in light of the latest regulatory developments in the Italian framework, with an extension of the aggregation perimeter prescribed for the REC. Currently, all members of the same REC must be connected to the same secondary substation (LV level) wihle in the future the REC will be able to include all users connected to the same primary station (MV level).

The Magliano Alpi team has sought to be hosted in the Smart Grid Interoperability Laboratory in Ispra to take advantage of its computational hardware resources, of its proprietary demand prediction models and of the expertise of its researchers in the areas of energy forecast.

The main objective of the activity has been the modelling of RECs in order to be able to estimate the amount of energy generated from renewable sources that is virtually shared among REC users. The developed model is capable to recreate an estimated configuration of a renewable energy community, based on real data sets of consumption and production of photo-

voltaic systems. The model can also consider external data such as weather conditions, seasons, number of active and passive domestic users, number of industrial prosumers, type of user habits, territorial extension of the CER. The configuration resulting from the model is used to determine the virtual flows of energy between the different members of the CER, allowing to determine the overall incentive paid by the Electricity Services Manager and ARERA.

The simulation of different compositions of renewable energy communities also gives the opportunity to identify the limits of installed power and contracted power for which the amount of shared energy is maximized. This limit is relevant for the territorial aggregators of users, in order to avoid oversizing of the community; this oversizing would have as an immediate effect the decrease of the incentive shared among the various members of the REC and therefore a decrease in active involvement of users in terms of modification of their consumption habits to maximize shared energy.

In general, the prediction of the energy profiles of the REC and of their associated financial incentive represents a fundamental element for analyzing the economic sustainability of current and planned investments on RECs. The preliminary results and insights obtained by the user group during the visit are already very promising but further work is planned in the near future, with the development of an open-source version of the developed forecast software that includes a graphical user interface and standard functions for import of data from the main databases (e.g. ENEL). The final objective is to develop a comprehensive and easy-to-use software package that can be adopted by other practitioners and interested users of the sector.

1 Lab-Access User Project Information

1.1 Overview

Title: Renewable Energy Community "Energy City Hall" of the City of Magliano Alpi (Italy)

Acronym: M-ECHall

Host infrastructure: JRC Smart Grid Interoperability Laboratory (Ispra)

Access period: from 21/02/2022 to 25/02/2022 and from 10/05/2022 to 13/05/2022

User group members: Matteo Lugano, Davide Ferrero and Sergio Olivero

1.2 Research Motivation, Objectives, and Scope

The Lab Access User project aims at tackling some of the most relevant technical and analytical challenges in the planning and operation of RECs, with a particular focus on the implications of the most recent developments in the Italian regulatory framework regarding the aggregation perimeter of the RECs. Taking advantage of the scientific expertise of the SGILAB team on energy forecast model and of the hardware computational resources available in tha laboratory, the objective of the project is to develop a software tool and conduct extensive simulations to predict the energy behaviour of RECs and evaluate their associated financial metrics. The analysis relies on historical data and an extensive use of Monte Carlo technique to predict the energy behaviour of RECs of different size and composition, accounting for seasonal and weather conditions. The capability of the REC to self-consume the energy generated by its renewable assets will be estimated considering different numbers of users and prosumers while accounting for the impact of different geographical extensions to assess for example the difference in performance between rural and urban areas.

1.3 Structure of the Document

This document is organised as follows: Section 2 briefly outlines the state-of-the-art/state-of-technology that provides the basis of the realised Lab Access (LA) User Project (UP). Section 3 briefly outlines the performed experiments whereas Section 4 summarises the results and conclusions. Potential open issues and suggestions for improvements are discussed in Section 5.

2 State-of-the-Art/State-of-Technology

Renewable Energy Communities are a relatively recent novelty in the areas of energy systems and analyses on their technical and economic performance are still at an early stage. In particular, we are not aware of any relevant study or tool that allows to model shared energy within renewable energy communities by considering load profiles in a stochastic way. Moreover, although electricity consumption is well known on a monthly basis, it is not always possible to obtain it with the hourly granularity which is necessary to compute the energy flows and the associated financial incentives as defined in the current regulation.

Most of the existing analysis tool for RECs are only able to quantify the aggregate shared energy over a whole year, on the basis of data of energy consumption over distinct tariff periods. However, these tools introduce a series of heavy approximations and do not provide an acceptable time granularity in their analysis. Moreover, all the aforementioned tools make a limited use of available historical data, with limited modeling of seasonal and weather trends and no implementation of the geographical correlation of renewable generation installed in the REC territory.

The work conducted during the lab visits aims at overcoming the above limitation and developing a comprehensive tool for energy prediction in REC, applying Monte Carlo techniques and the modelling and hardware resources available in the SGILab to conduct an extensive numerical analysis on RECs performance.

3 Executed Tests and Experiments

3.1 Test Plan, Standards, Procedures, and Methodology

Test Plan

The overall plan of the activity entails the creation of a software platform for the evaluation and estimation of shared energy within a REC, to be followed by a numerical analysis on the performance of RECs of different size and characteristics. The analytical tool to be developed aims to forecast the amount of renewable energy that is locally generated in the REC and consumed locally, taking into account a wide array of different factors:

- Number, size and type (residential/commercial/industrial) of REC users
- Location and geographical extension of the REC
- Seasonal and weather trends

The activity has been articulated in two different visits to the SGILAB in Ispra:

- First visit (February 2022): realization of a first software prototype, with the implementation of the basic functions of the forecast tool and the first preliminary numerical analysis.
- Second visit (May 2022): refinement of the software prototype, with the inclusion of refined forecast models, the development of additional software features and more extensive simulation results.

Test standards, procedures and methodology

The main objective of the activity is the creation of a simulation tool for RECs that is capable of estimating their self-consumption for a wide array of parameters and conditions. The training data of the model include historical energy profiles from public database and ad hoc profiles generated by the JRC proprietary model for demand forecast, based on linear regression and neural network techniques. The forecast is performed with Monte Carlo techniques: for a prescribed prediction scenario, different instances of REC behaviour that are consistent with the scenario parameters (e.g., season, number and type of members, geographical extension of REC) are randomly selected. The relevant REC quantities and metrics (e.g. aggregate load, aggregate renewable generation, self-consumed energy) are estimated as the average of the same quantities in the different generated instances.

The development of the analytical tool was conducted in the Matlab environment and was divided into the following phases:

1. Input data processing

   This step covers all the necessary actions for the creation of the energy profile database that is later used in the prediction phase. This includes:

   a. *Data import*: ad-hoc functions have been developed to import the historical REC data from the available public databases and convert them from the original format (csv) to Matlab data files

   b. *Data integration*: the historical data are integrated with ad-hoc profiles generated by the proprietary JRC demand forecast model
   c. *Definition of reference users*: typical users and prosumers are identified from the database and are used as distinct REC member types, to be used in a subsequent phase to populate the virtual REC under study. Rescaling operations are applied to the profiles in order to consider users of different sizes.
   d. *Data processing and filtering*: the imported data are filtered to remove undesired outliers or spikes in the measured profiles, due to measurement or recording errors. Historical time profiles are also divided into separate daily profiles. The generation and demand data are interpolated according to the desired time step (e.g. quarter-hourly) and are sorted according to the type of user and the season of the year.

2. Prediction phase

   This step implements the Monte Carlo simulations which are used to forecast the REC energy behaviour:

   a. *Sample database definition*: the available dataset is restricted to only consider the samples that are consistent with the chosen prediction scenario in terms of types of customers/prosumers and seasons.
   b. *Iterated extraction*: random load/generation profiles are extracted from the limited sample database for each of the consumers and prosumers assumed to operate in the REC. In the single simulation instance, the PV profiles of the different prosumers are chosen within a (randomly selected) percentile interval of daily energy generation, to account for weather correlation. Similarly, the prosumers of the REC are uniformly distributed in subareas of equal geographical areas. It is assumed that the correlation in PV generation for all the prosumers within each area is equal to one and only a single PV generation profile is considered for these prosumers. This random sample extraction is iterated a certain number of times, depending on the amount of available data and on the chosen trade-off between simulation time and forecast accuracy.
   c. *Average evaluation*: The relevant simulation outputs (i.e. aggregate load and PV generation, imported and exported energy, self-consumed energy) are computed as the average of the different simulated samples.

3. Elaboration of results

   The Monte Carlo simulation described in the previous step can be performed a single time to consider a specific scenario. Alternatively, it can be used to perform sensitivity analyses over some parameters of interest, replicating the simulations over the parameters space to evaluate the impact of the parameters change on the output variables of interest, e.g. the percentage of renewable generation that is shared within the REC.

3.2 Test Set-up(s)

The tests carried out in the first session used as training data of the predictive model a public database[1] of generation and demand profiles from small residential and commercial users (both user and prosumer). Within the database, 3 different types of prosumers (with different assets and installed power of photovoltaics) and 2 different types of consumers (each with different load types and consumption patterns) have been selected. These standard users have been replicated to build a larger population within the REC (from a few dozen to hundreds of different users). The Monte-Carlo simulations were then performed by varying the main parameters of interest (in particular number of users and geographical size) and considering a number of stochastic realizations equal to 200 for each set of parameters, in order to obtain an acceptable trade-off between computation time and accurate modeling of the intrinsic stochastic variability of the generation and demand profiles.

During the second session, industrial user data was implemented and simulations were iterated again. Considering that the industrial user is consuming an higher amount of electricity and its consumption profile is different than a household user it is possible to see changes in the overall RECs consumption profile integrating industrial users in the REC. The industrial user has an almost flat adsorption profile during the working time that goes from 7AM to 18PM with a slight decreasing during the lunch hours; on the other hand the overall household load profile has a peak in the early morning and in the evening while in the central hours of the day load is lower. Assumed that the magnitude of the power imported by the industrial user is almost ten times higher than an household user, a shifting of the power peaks from the early morning and late evening towards the central hours of the day can be noticed. This leads to a best employment of the renewable energy shared on the grid.

3.3 Data Management and Processing

Available data from the online database[1], from the Magliano Alpi REC and from DSO website need to be elaborated to obtain a usable dataset for simulation. Different activities have been conducted over each set of data:

1. Household_data dataset elaboration

   Original dataset was composed by some small industrial users, some household users and prosumers, and some household prosumers equipped with a storage system. In order to consider consistent consumption profiles, the simulations conducted during the first visit of the user group have neglected small industrial users. Prosumers with storage systems were also neglected because the available database did not provide any indication about the state of charge of the batteries. As a result, it was not possible to determine from the available data the net load of the corresponding users.

   After the appropriate users/consumers entries in the database were selected, their associated energy profiles were validated. During this process, spikes in energy flows resulting from measurement and communication errors were detected. Since the measures availa-

[1] https://data.open-power-system-data.org/household_data/

ble from the database represent the integrated value of energy that is being imported, exported and produced, the quarterly-hour difference was calculated in order to obtain the energy flow. Anomalous spike values were then replaced with the maximum energy that can be imported or exported to the grid in relation to the contracted power of the household user (i.e. a 4,5 kW contracted power can import at most 1.125 kWh every quarter).

To better combine and analyse the data of the individual users, accounting for weather conditions and territorial correlation (i.e. holidays or other events), it is preferable to consider samples from each user that span over the same time interval. For this reason, a time series trimming of some users has been performed in order to have comparable intervals of data.

2. Magliano Alpi dataset

   Magliano Alpi dataset was taken into account only for the winter period simulation, as this was the only complete season with available data from REC members. Since the available raw data from Magliano Alpi REC has measurements with a variable sampling time, a timestamp elaboration with the average energy exchanged every quarter has been performed.

3. Industrial data available from DSO

   For contracted power higher than 55 kW, it is mandatory for Italian DSOs to install meters that can register energy measurements every quarter-hour. This data is than stored on DSOs websites for a period of at least 12 months. These data can be downloaded in .csv format, with each file containing one month of energy flow data in a given direction (i.e. a prosumer in a single month can downloaded one file for the imported energy, one for the exported and one for the produced energy by the PV). Once files have been downloaded they are renamed with the POD code and the energy direction (i.e. Imported energy by POD XXX will be renamed as XXX_I.csv while energy exported will be XXX_E.csv and produced energy will be renamed as XXX_P.csv). Software can then generate a single file for each user, sorting the timestamp of the energy flow and the direction. The format of the final output file is the same of the first DB, in order to treat data in the same way.

After the raw data has been elaborated, the software simulates the REC behavior and calculates the energy exchanged between producers and consumers on a quarter-hour and hour basis. As descripted at point 3.2, simulations are conducted over different number of users, seasons and geographical extension. For each simulation the energy produced, shared and consumed is calculated. For a compact characterization of the simulation results, performance indexes of the REC are defined and calculated aspercentages of shared energy and consumed energy over the produced energy.

4 Results and Conclusions

4.1 Discussion of Results

Below some representative results of the analysis conducted during the first visit at the SGILab. In particular,Figure**Errore. L'origine riferimento non è stata trovata.** and **Errore. L'origine riferimento non è stata trovata.** represent the average daily consumption and demand profiles, respectively, of a fictitious REC composed of 400 consumers and 80 prosumers, with a geographical extension of 576 km^2.

Considering the statistical analysis conducted in (Richard Perez, 2012), it has been assumed that the minimum distance between PV plants that guarantees complete daily uncorrelation of their generation profiles is equal to 8 km. For this reason, the geographical extension of the REC (assumed to be a square) has been divided in 9 smaller squares with a 8 km side. which The chosen number of users and prosumers has then been uniformly distributed over the single sub-areas.

It can be seen from these figures that the public data used for the preliminary studies represent in a rather clear way some of the fundamental load and generation trends to be considered in the estimation of the self-consumed energy of the REC. Note in**Errore. L'origine riferimento non è stata trovata.** Figure 2 that, on a typical winter day, the photovoltaic production of the REC can be entirely self-consumed. On the other hand, it can be seen in Figure 1 that in summer, due to a lower load and a higher PV generation, only 50% of the energy generated is self-consumed on site.

The energy that is actually shared within the REC has been estimated on the basis of two fundamental parameters(total contracted power of the CER and installed photovoltaic power) which in fact are indicative of the number of users and the ratio between the number of users and prosumers. Figure **Errore. L'origine riferimento non è stata trovata.** confirms what was discussed in the previous paragraph, with a percentage of shared energy that is significantly higher in winter. In addition, it can be noted that this percentage decreases significantly as the contracted power decreases, while there is an opposite trend (albeit of a smaller amount) with respect to the installed photovoltaic power. Seasonal differences are of the opposite type when considering shared energy in the REC as a percentage of PV generation, as presented in Figure 4. It should also be noted that this percentage is substantially constant (equal to about 40%) in winter, while in summer are evident the same trends already discussed.

The same simulative approach has also been applied to a different REC that includes 5 large industrial prosumers. The results in terms of average daily energy profiles (in summer and winter) and amount of self-consumed energy as percentage of total export and PV generation are presented in Figure 5-Figure 8.

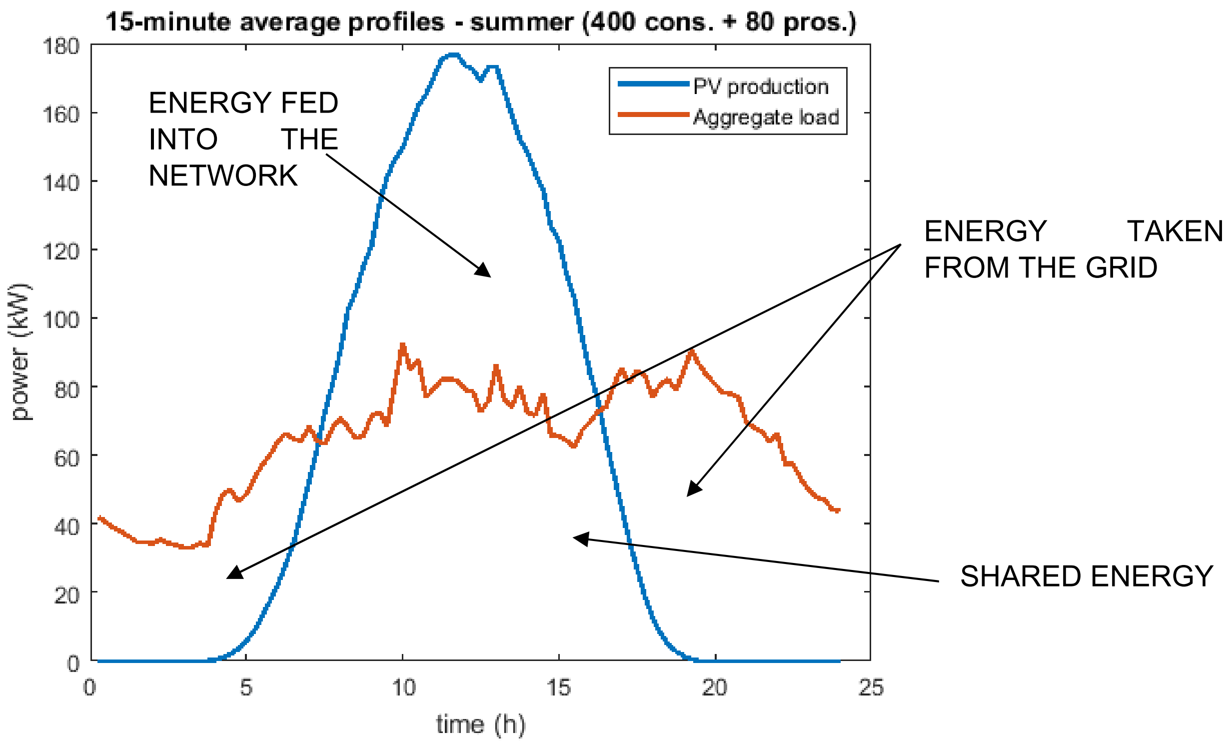

Figure 1: Estimated average REC daily profiles of generation and load in summer

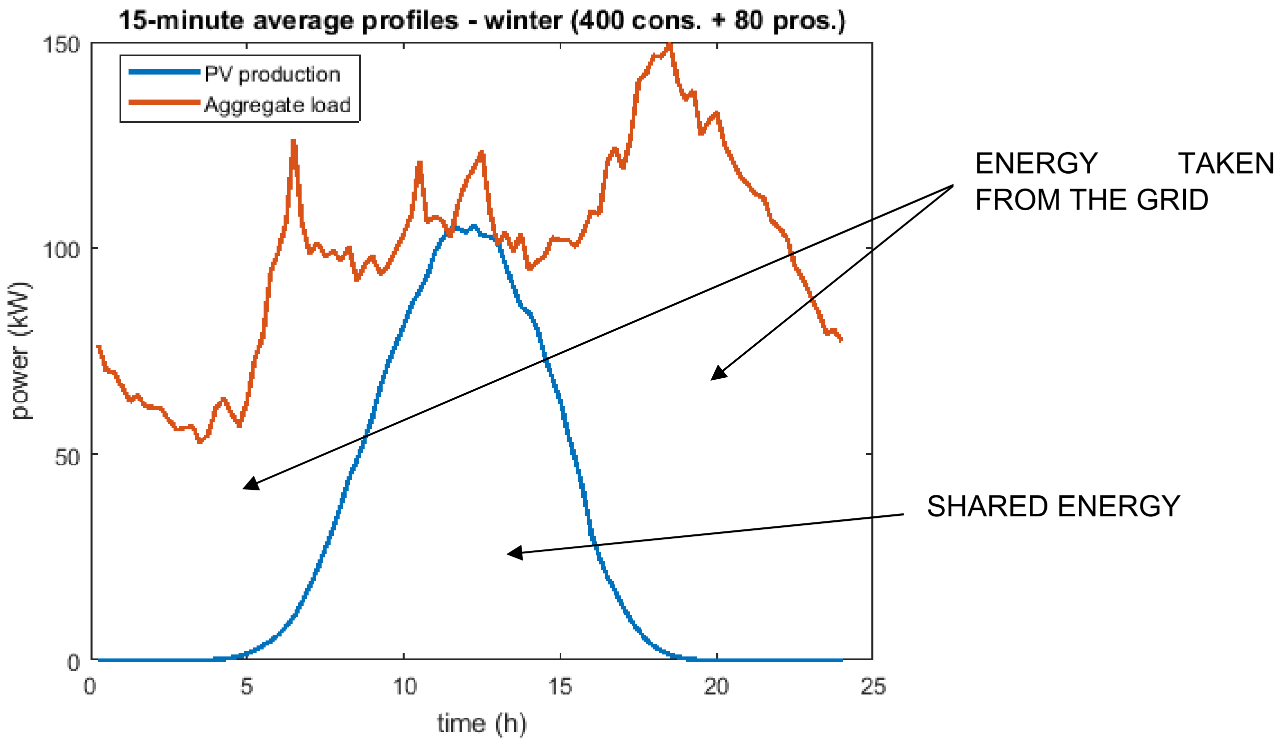

Figure 2: Estimated average REC daily profiles of generation and load in winter

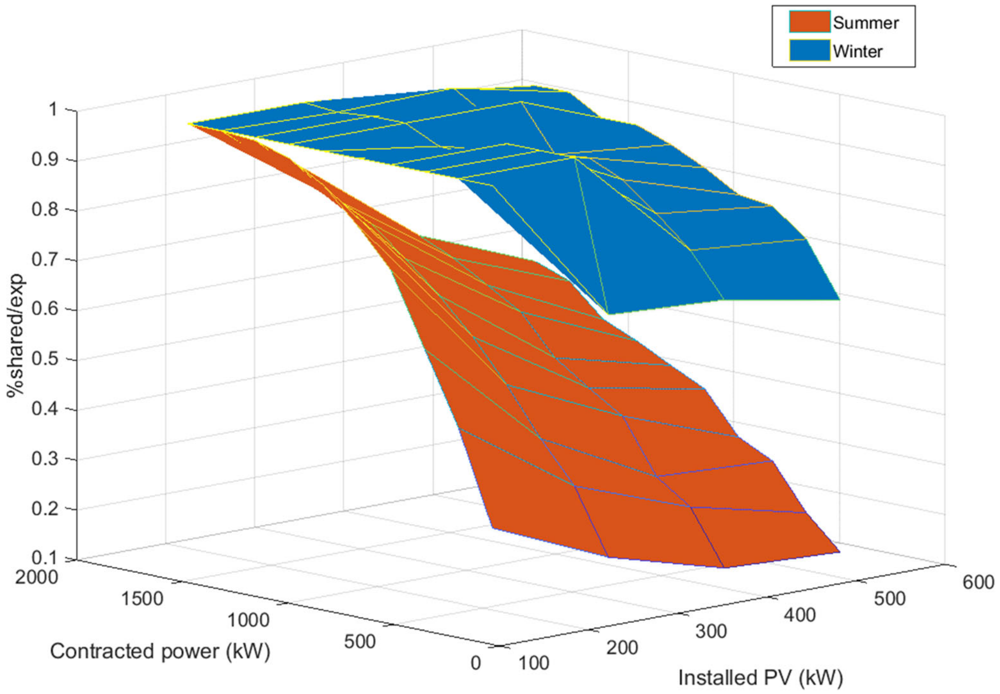

Figure 3: Percentage of the REC exported energy that is self-consumed

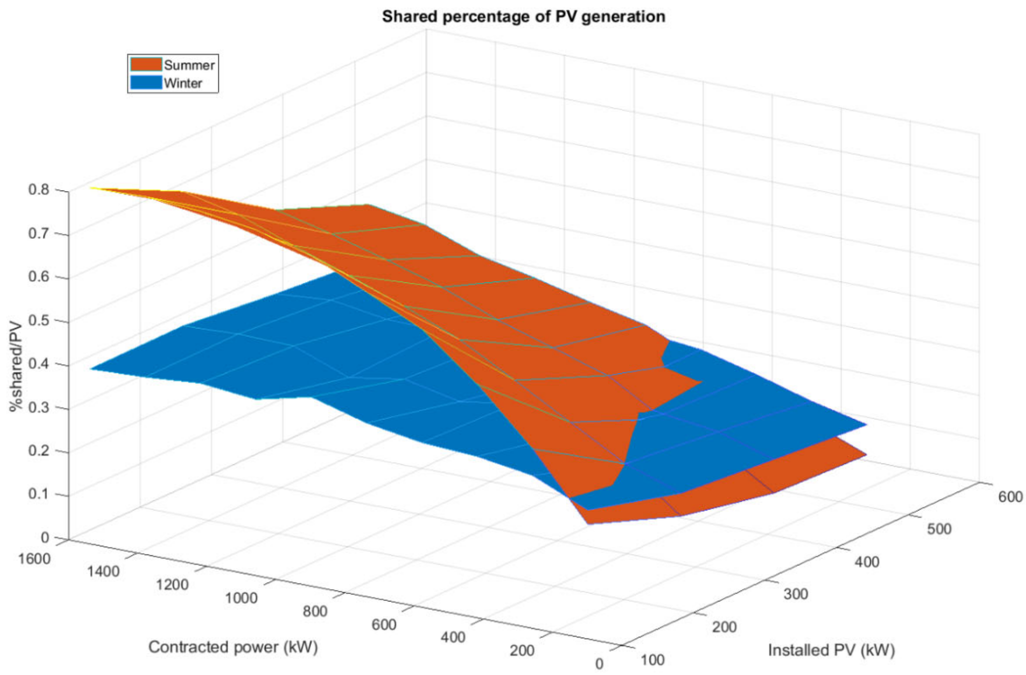

Figure 4: Percentage of the REC PV generation that is self-consumed

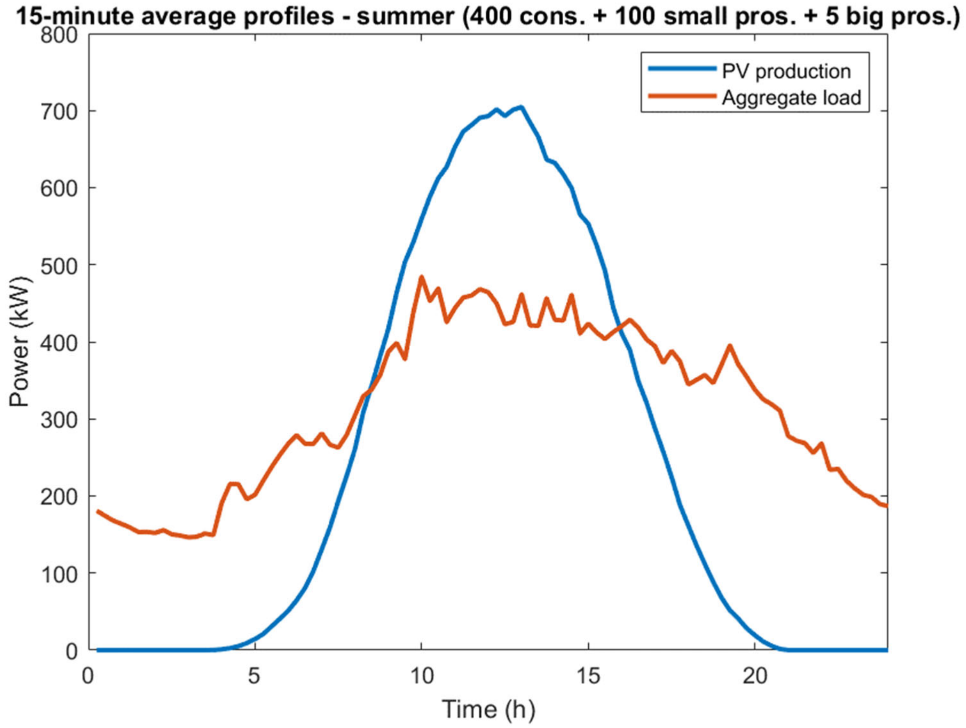

Figure 5: Estimated average daily profiles of generation and load in summer (REC with large industrial users)

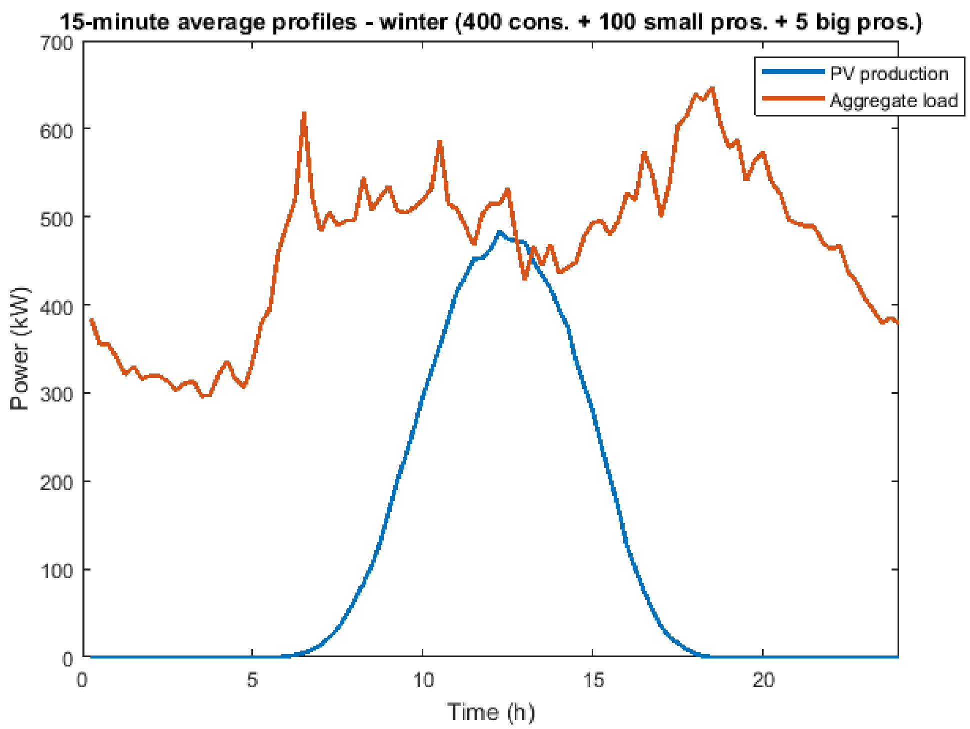

Figure 6: Estimated average daily profiles of generation and load in winter (REC with large industrial users)

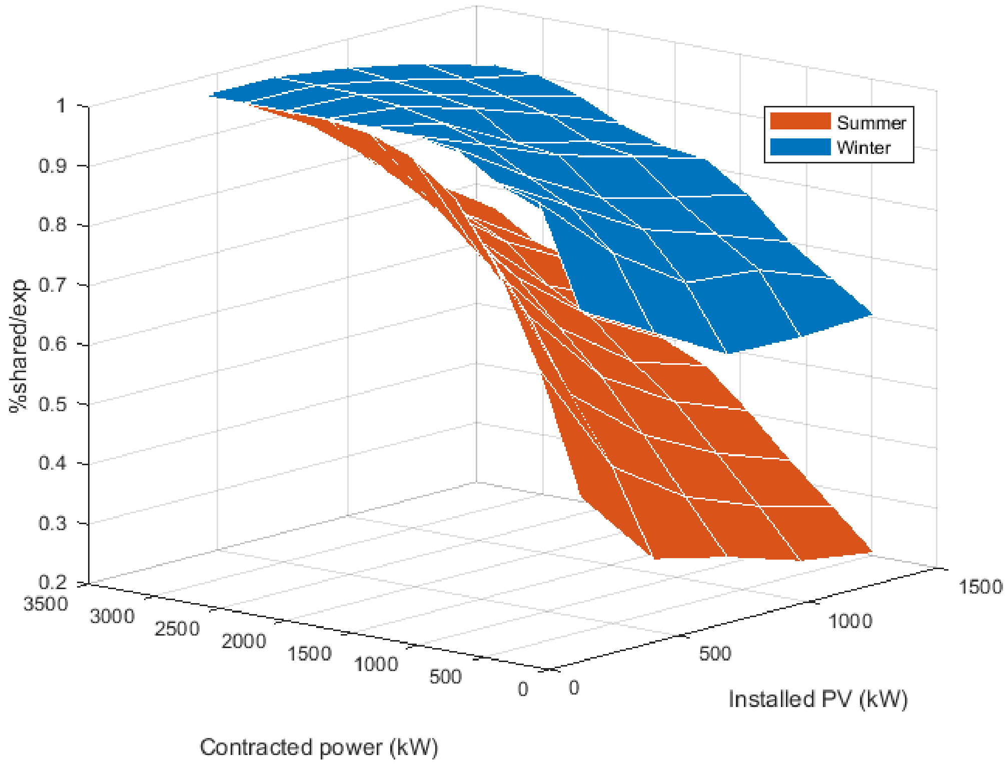

Figure 7: Percentage of the exported energy that is self-consumed (REC with alrge industrial users)

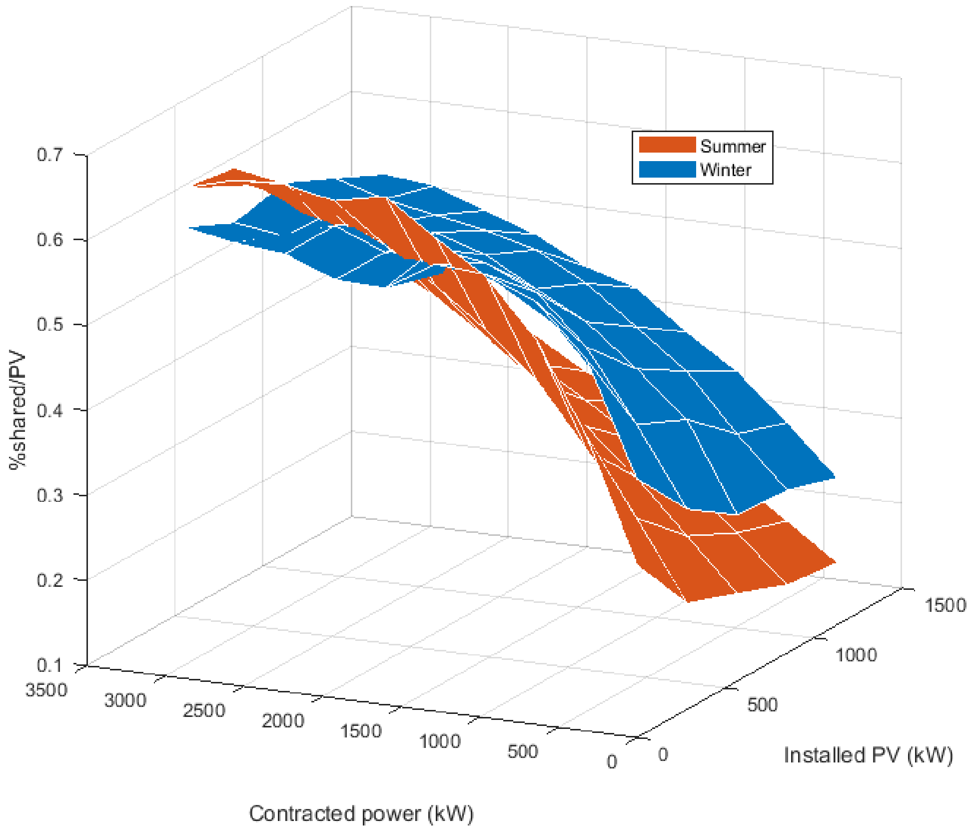

Figure 8: Percentage of PV generation that is self-consumed (REC with large industrial users)

4.2 Conclusions

The ERIGrid 2.0 Lab Access programme allowed the development of an important tool to estimate the behaviour and performance of Renewable Energy Communities. Relying on the scientific expertise, proprietary models and computational resources of the SGILab, the visiting activity has led to the creation of a versatile software that can forecast the main energy metrics of RECs of different sizes and composition, accounting for some of the key interdependencies in the energy behaviour of their different users and providing the modelling flexibility to evaluate the impact of expected regulatory changes. These results can support the activity of public and private entities which might be interested in the creation of new RECs but require preliminary information and guidance on the optimal composition of the community and associated financial incentives. The software can also provide useful indications for the regulators, indicating which population sizes and geographical extensions of the RECs lead to a better local utilization of the available renewable generation. For these reasons, further work is planned to be conducted on the software, in order to create an open-source version endowed with graphical interface and ad hoc data import/export functions that is easier to use by external third parties.

5 Open Issues and Suggestions for Improvements

One of the extensions of this software is the opportunity to better interact with the data generated by the different Renewable Energy Communities (REC) in operation in Magliano Alpi and in the Cities that signed a Cooperation Agreement with Magliano Alpi (whose number is increasing). This feature allows to tune the hypothesis at the basis of these simulations. Calculating the differences between real data and simulated data can provide important information about the behaviour of RECs. An open point is to understand if there is a strict correlation between users consumption habits and the overall shared energy in a mixed industrial-domestic REC.

The incentive sharing algorithm is at the base of the users commitment to the RECs consumption rules. This tool can boost the investigation of an dynamic algorithm for optimal energy sharing, indicating to the users the ideal power consumption profile in relation to electricity prices, seasons, weather forecast, et cet.

Another aspect that can be studied is the opportunity to create a dataset in which electricity consumption is related to sociological parameters, such as the number of people living and operating in the individual households, their lifestyle habits and the willingness to change their energy behaviour in order to adhere to a rewarding mechanism based on virtual self-consumption. This correlation would allow to create a simulation tool that is directly based on users rather than on their energy data.

References

Richard Perez, S. K. (2012). Short-term irradiance variability: Preliminary estimation of station. Solar Energy 86*, 2170–2176.*

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